Flow Statistics for Tailraces below Dam Spillways

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Abstract. A number of ERDC models use Video Tracking Systems (VTS) to document the pathways of lighted floats released in the tailrace area below model dams. Because of shifting eddies and other flow instabilities, floats released at the same point often take quite different pathways. Distances of as much as a thousand feet (prototype) can separate successive pathways. Even when pathways are similar, velocities along those pathways are often different.

This variability has implications for the survival of juvenile salmon that are swept along with the flow. One pathway may expose the juveniles to risks such as heavy predation whereas the other possible pathways may be much less risky. The transit time through the risky areas will also affect survival rates.

VTS provides an economical way to explore this variability in pathways. For instance, many successive floats can be released at exactly the same place in front of a particular spillway bay. For that release point, the processed results can provide answers to questions such as:

- What is the probability that a float (or a parcel of water containing juvenile fish) will pass through a particular area?
- How much time does a typical float take to pass through that particular area?

Actual model results are presented graphically on maps of a dam tailrace. These results illustrate the insights that can be gained by using VTS in this way.

The Little Goose Dam. Data for this study were collected in a physical model of the Little Goose Dam. The actual dam is located in southern Washington on the Snake River. It is about 250 miles east-northeast from Portland, OR. The prototype is comprised of a spillway, powerhouse, and lock. The spillway has eight 50-ft-wide bays and the powerhouse has six units, each about 90-ft-wide. The 86-ft by 668-ft lock has a maximum lift of 101 ft. An 850-ft-long abutment connects the spillway to the north shore of the river. The general configuration of the dam can be seen on Figure 1.

Each year millions of salmon move through the structure, adults moving upstream and juveniles moving downstream. The dam has three fish ladders, which mainly benefit the adults. Some of the juveniles are collected above the powerhouse and returned to the river by an outfall in the tailrace.

The Hydraulic Model of the Dam. A physical hydraulic model of the Little Goose Dam at 1:55 scale is located at the Waterways Experiment Station of the U.S. Army Engineer Research and Development Center in Vicksburg, MS. The Coastal and

Hydraulics Laboratory operates this model under the sponsorship of the Corps' Walla Walla District.

This 60-ft by 120-ft facility reproduces portions of the upstream and downstream shorelines and riverbed. The spillway, powerhouse, and fishways are modeled both physically and hydraulically. The lock is physically modeled but is not hydraulically operational.

The experimental results given below, although collected in the model, are all reported in prototype (i.e., real world) units.

The Video Tracking System (VTS). An eight-camera, overhead particle-tracking system documents water trajectories and velocities. These video cameras track lighted floats within a 2600 ft by 2000 ft area of the tailrace. A PC acquires the data from all the cameras. Because of the draft of the floats, these measurements represent a weighted-average of flow velocities to depths of about 6 to 9 ft. Typical experimental procedures involve releasing a float near the dam and using VTS to track its path until it moves out of camera range.

Post-processing the VTS data yields two tables of information: 1) the float coordinates as a function of time and 2) velocity vectors (magnitude and direction) as a function of position. Both sets of position information are plotted automatically on AutoCAD base maps, which superimpose the VTS results on drawings of the dam and the adjacent shorelines. Figure 1 shows such a plot of velocity vectors. When using AutoCAD to view these drawings on a computer monitor, the VTS software permits "clicking on" a point along the float track to get its time and coordinates or clicking on a vector to get its time, coordinates, magnitude, and direction.

Experimental Procedures. For this study, we set up the model with the two central bays of the spillway discharging 7,000 cfs each and the other six bays discharging 4,700 cfs each. The powerhouse discharge was from the southernmost unit only, at 13,300 cfs. Water levels in the upstream pool and in the tailrace were kept constant throughout the study (values are shown on the figures).

Then, we released a lighted float at a point about 550 ft downstream from the spillway crest and along a line through the center of the spillway. A circle on Figure 1 indicates the release point. The VTS acquired points along the path of the float at intervals of about 33-second (prototype) until the float moved out of camera range. Then, the process was repeated 35 more times to yield 36 separate and independent float tracks. The actual release points for all 36 floats were within 20 ft of the intended starting point.

Post processing of the VTS data yielded the tables and AutoCAD drawings mentioned above. Additional processing of those products yielded information on the percent of the floats that entered various areas within the tailrace, times for the floats to pass through the monitoring area, and percentage of the floats that spent more than a certain amount of time in a given area. Those results are discussed below.

Velocity Vectors. Figure 1 shows velocity vectors for 42 percent (15 out of 36) of the floats. Each vector represents a separate calculation of the velocity magnitude and direction between two successive points along the float's track. Each vector points in the direction of flow and its length is proportional to the magnitude of velocity. In addition, the color of a vector indicates the velocity range in which it falls. Velocities greater than 8 fps have red vectors as indicated by the legend at the upper right.

As the figure shows, these floats traveled in a fairly narrow band, about 400-ft across at its widest. Magnitudes were quite variable, from less that 1.5 fps to greater than 8 fps. The smallest velocities occurred along the south edge of the band and the largest along the north edge. The degree of variability shown here will not surprise engineers who are knowledgeable about the tailraces below large dams. However, Figure 1 shows only 42 percent of the floats. What the other 58 percent did **is** surprising. See Figure 2.

Figure 2 shows velocity vectors for 58 percent of the floats. For comparison, red lines indicate the limits of the envelope in which the other 42 percent traveled. Some floats traveled to the north shore and hugged that bank until they exited the viewing area. Others headed southward and exited the southern boundary of the viewing area. At the downstream limits, those pathways were as much as 1,500 ft apart. The occasional loops in the tracks indicate floats that were caught in eddies. One float even headed southward and upstream and became trapped against the front of the powerhouse.

The extreme variability indicated by Figure 2 has implications for fluid measurements made in the tailraces below large dams. Whether measurements are made in a model or in the prototype, a small number of measurements is unlikely to reveal the full extent of the variability. At a number of locations on Figures 1 and 2, float tracks can be seen to cross each other. Where crossings occur, velocity directions – and probably magnitudes, too – are changing with time.

Juvenile salmon transiting the tailrace on their journey downstream to the Pacific Ocean face a risk of being eaten by predators. The degree of risk is related to whether the flow carries them into areas where predators congregate. To the extent that the juveniles go where the water goes, the VTS float tracks can be used to help evaluate the risk. As a first step, we need to define the areas of the tailrace where predators may be concentrated. As examples, the following section gives two (out of many) possibilities for defining such areas.

Comparison Information. Figure 3 shows average water depths in the Little Goose tailrace. The area has been arbitrarily divided into a grid of 200-ft by 200-ft squares. The average depth within each square is indicated by color. The deepest water is blue and the shallowest water is red. A prominent shallow area is indicated by nine red squares clustered around grid coordinates K-8. Predators may favor the shallow areas, where they can hold station behind streambed features or within the near-bed boundary layer. From there they can dart upward a relatively short distance to eat juveniles being swept by overhead.

Figure 4 shows average current velocities displayed on the same square grid used on Figure 3. The color-coding uses blue for velocities greater than 4.5 fps and red for velocities less that 1.5 fps. The velocity data for this figure were derived from a separate VTS study, involving a total of 81 floats and 26 different release points spread out over the tailrace area. A prominent area of low velocities exists at the southwest corner of the grid. Predators probably don't spend much time in areas where velocities are greater than 4.5 fps: they have to expend too much energy to hold station there. Low velocity areas will be much more attractive to them, especially if food is readily available.

Areas of greatest predation risk can be defined by procedure similar to those used on these two figures. Obviously those areas don't have to be defined by squares. And, a host of other variables (or combinations of variables) might be used, such as water temperature, oxygen content, streambed characteristics, etc.

The following sections illustrate how the VTS data can be related to areas of increased predation risk.

Results – Percent Entering. Figure 5 shows the probability that floats starting at the release point used here will enter a particular 200-ft by 200-ft square within the grid. The percent probability is indicated by color. As indicated by the red color, between 50 and 75 percent (18 to 27 floats out of 36) can be expected to enter the two squares with grid coordinates C-7 and D-7.

The probability is 25 to 50 percent that floats will enter a particular green square in the continuous green zone that extends from C-6 to M-4. Comparison to Figures 3 and 4 indicates that this green zone generally coincides with water depths greater than 24 ft and current velocities greater than 3 fps. Hence, if the reasoning in the preceding section is valid, those green squares may be zones of reduced predation risk.

For the previously mentioned prominent red areas of shallow depth or low velocity, the probability is seen to be 0 to 25 percent that a float (or juvenile salmon) will be swept into a particular square. This range of probability is too broad to be particularly instructive, but the same procedures could easily be used to set much finer probability ranges.

An alternative analysis, not shown on the figures, indicates that 44 percent of the floats will enter some portion of the red, nine-square, shallow area on Figure 3. Twenty-five percent of the floats will enter some portion of the red, low-velocity area in the southwest corner of the grid on Figure 4. If these are in fact high predation areas, then substantial portions of the juveniles carried along by the flow may be subjected to elevated risk levels.

Results – Times. Figure 6 shows the percentages of the floats that spent less than a given number of minutes in the tailrace area within 2,700 ft of the dam. For example, 53 percent of the floats exited that area within 13 minutes. The "consistent 42 percent" shown on Figure 1 were within this group. Floats with more erratic paths took longer, 25 percent (9 out of 36) taking more than 29 minutes. Because predator fish congregate in such areas below dams, the longer the transit time, the greater the risk faced by juvenile salmon. Information like that presented on Figure 6 may be useful in quantifying the potential risk.

In a similar way, the VTS data can be applied to smaller areas. Figure 7 shows the concept applied to the 200-ft by 200-ft squares considered earlier. The colors indicate the probability that a float will spend more than 2 minutes in a square.

For instance, 42 percent (15 out of 36) of the floats spent more than 2 minutes in square D-7, which is assigned a red color in accordance with the color legend. A time other than 2 minutes could easily have been used as the criteria. However, the average time that a float spent in a square that it entered was 1.5 minutes, so a residence time over 2 minutes is quite long. An assessment of the risks for juvenile salmon might consider whether the squares in which they have a substantial probability of spending a long time are also likely to contain many predators.

Conclusions. In the tailraces below large dams, the surface pathways taken by parcels of water can vary widely with time. A small number of measurements, either in the prototype or in a model, may not reveal the extent of that variability. An understanding of the risks faced by juvenile fish transiting the tailrace should consider the extent to which that variability might carry them into predator-infested areas.

The use of a Video Tracking System in a model provides an economical means to make enough measurements to understand the variability and to express aspects of it in statistical terms. To the extent that juvenile fish go where the surface water goes, the risks to which they will be exposed can be assessed by combining VTS results with information about where predators are likely to be.

Dam operations can be controlled to alter flow patterns in the tailrace. Possibilities include: 1) changing spill patterns (the sequence of spillway gate openings), 2) changing the division of total discharge between powerhouse and spillway, and 3) changing the number and positions of powerhouse units that are in operation. The possible effects of these changes can be evaluated in physical models using Video Tracking Systems and the analysis procedures describe above.

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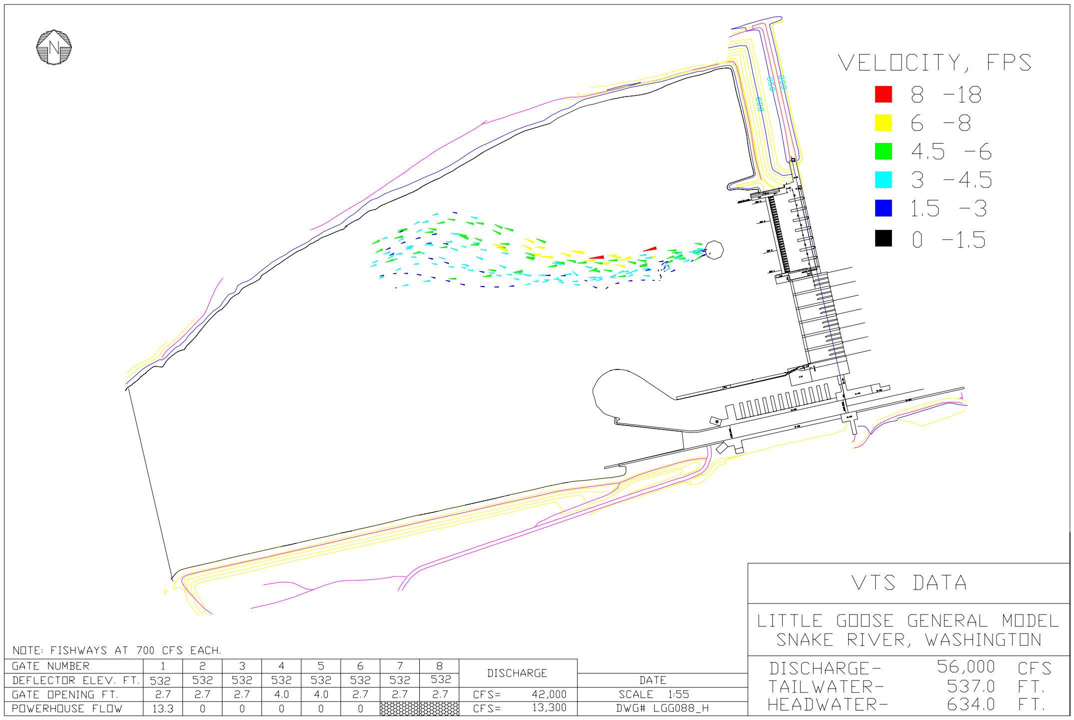


Figure 1. Velocity Vectors, The Consistent 42 Percent

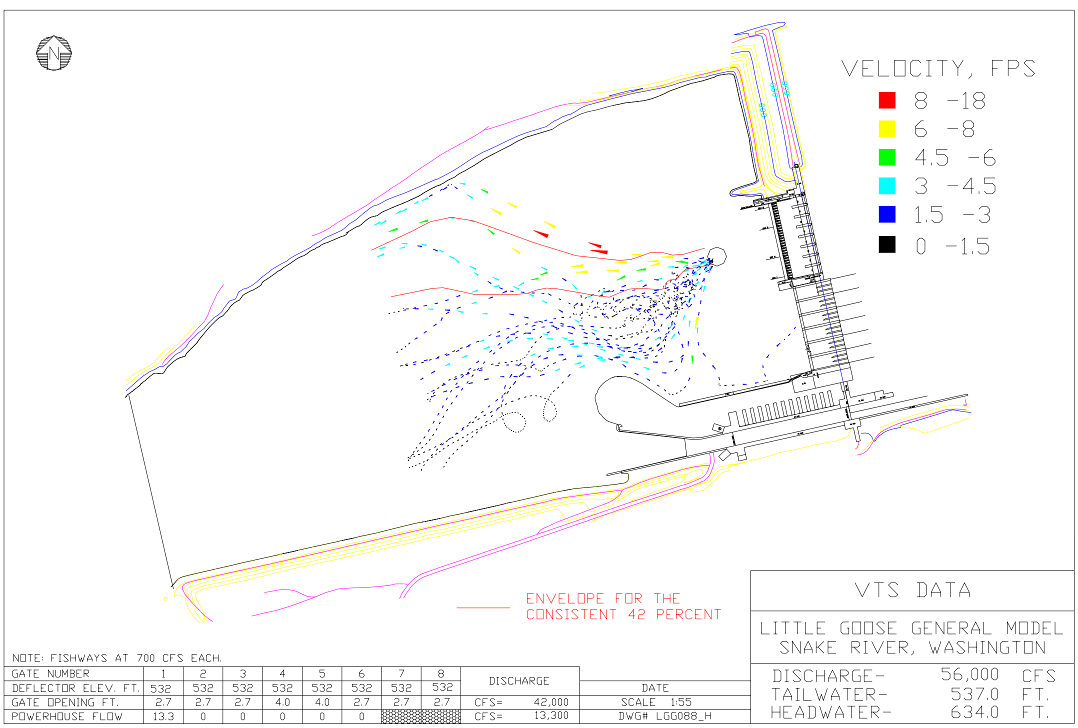


Figure 2. Velocity Vectors, The Other 58 Percent

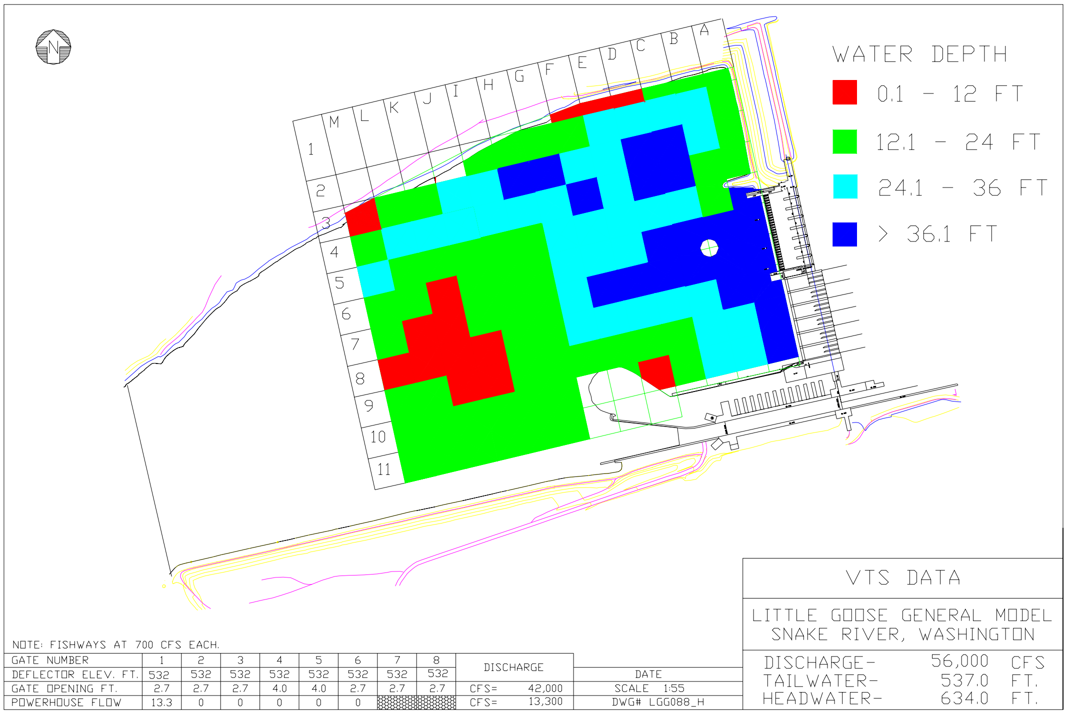


Figure 3. Average Depths

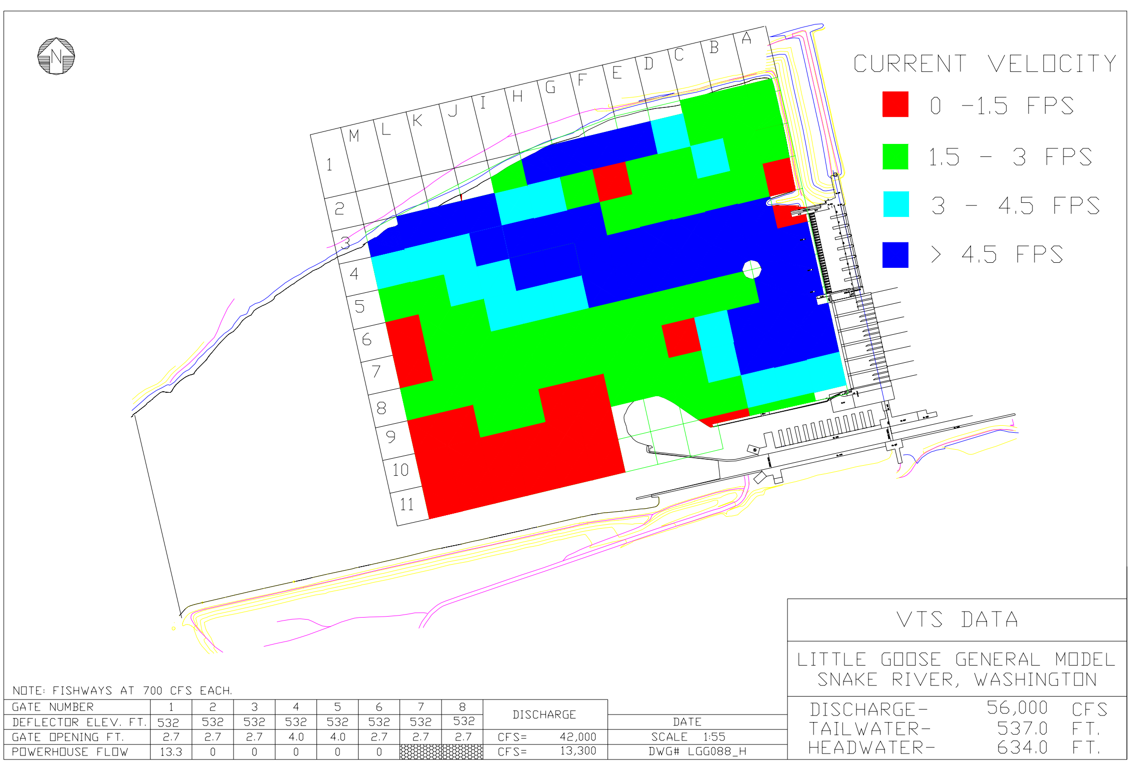


Figure 4. Average Current Velocity

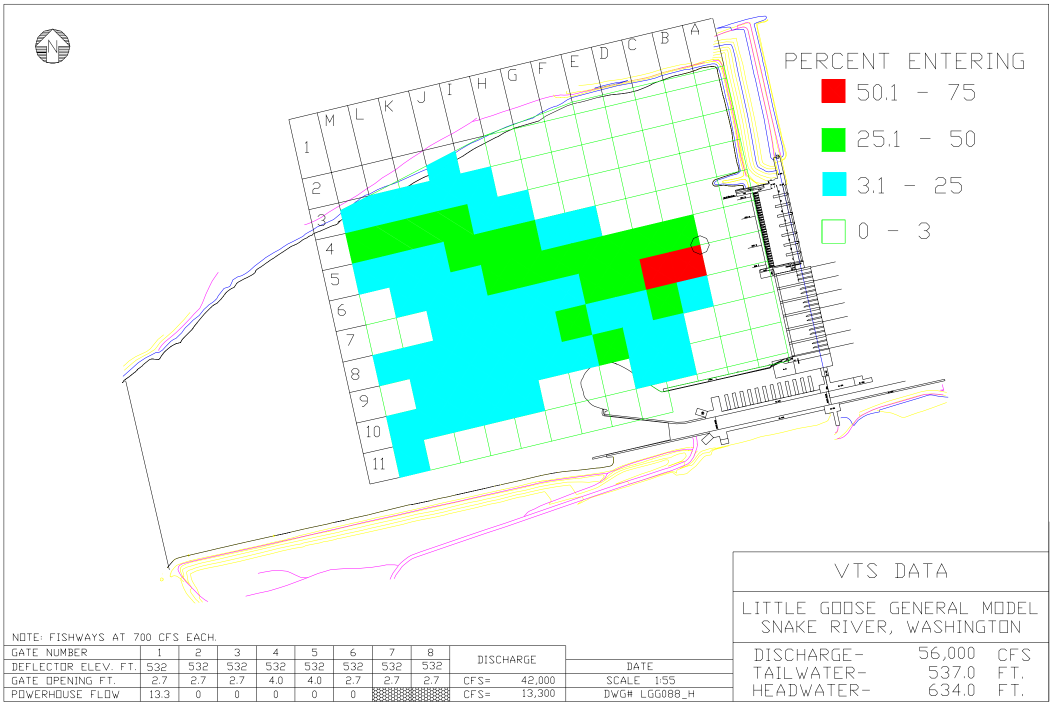


Figure 5. Percent of Floats Entering Square

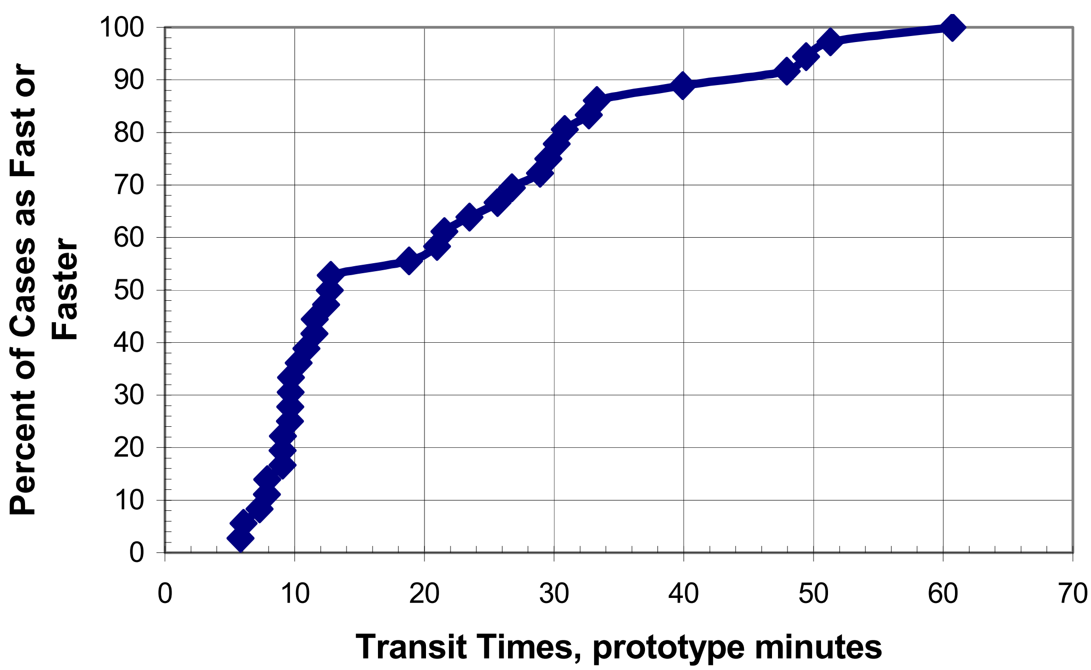
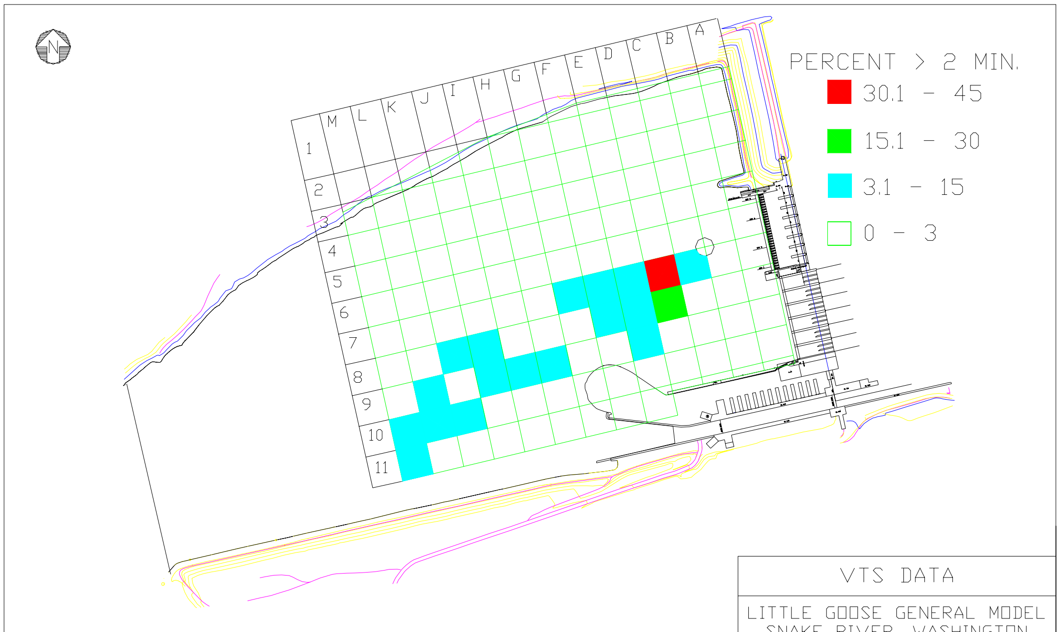


Figure 6. Time to Exit the Region within 2,700 ft of Dam



GATE NUMBER	1	2	3	4	5	6	7	8	DISCHARGE	
DEFLECTOR ELEV. FT.	532	532	532	532	532	532	532	532		DATE
GATE OPENING FT.	2.7	2.7	2.7	4.0	4.0	2.7	2.7	2.7	CFS= 42,000	SCALE 1:55
POWERHOUSE FLOW	13.3	0	0	0	0	0			CFS= 13,300	DWG# LGG088_H

Figure 7. Percent of Floats Spending More Than 2 Minutes in a Square